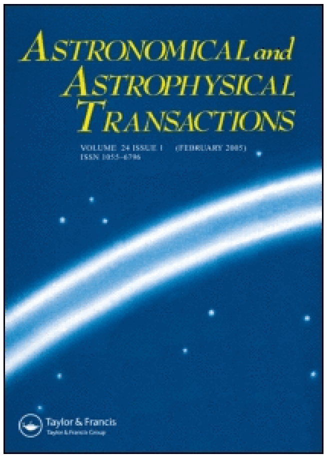

Astronomical & Astrophysical Transactions
The Journal of the Eurasian Astronomical Society
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713453505

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Online Publication Date: 01 March 1998
To cite this Article: Shchekinov, Yu. A. and Bogosova, Ya. B. (1998) 'On star formation in edge-on galaxies', Astronomical & Astrophysical Transactions, 16:1, 1 - 14
To link to this article: DOI: 10.1080/10556799808208138
URL: http://dx.doi.org/10.1080/10556799808208138

Astronomical and Astrophysical Transactions, 1998,
Vol. 16, pp. 1-14
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ON STAR FORMATION IN EDGE-ON GALAXIES

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(Received August 27, 1996)

Extraplanar diffuse ionized gas in edge-on spiral galaxies is thought to be an indicator of star formation activity in the parent galaxy. We argue that the z-extension and morphology of the diffuse ionized gas is expected to vary for different galaxies even with equal star formation rate per unit area, if they have different densities in the gas discs, different gravitational accelerations, and their OB associations have different luminosity distributions, We slow that the thickness of the gaseous halo is not a monotonic function of galactic luminosity: at high luminosities stellar activity supports a thick disc rather than an extended halo. The observed correlation between the extension of the extraplanar gas and the FIR luminosity of the underlying discs in edge-on galaxies can be explained either if the mechanical luminosity of SNe explosions is restricted from above by the values 0.3–0.5 $\times 10^{-4}$ erg cm^{-2} s^{-1}, or if the star formation activity in the underlying galaxies is distributed non-homogeneously through out their discs.

KEY WORDS Diffuse ionized gas, galactic gaseous halos, edge-on galaxies, star formation

1 INTRODUCTION

The search for extraplanar diffuse ionized gas (DIG) in external galaxies carried out during recent years, starting from the detection of DIG in NGC 891 (Dettmar, 1990, Rand *et al.*, 1990), has illuminated the principal physical mechanisms able to provide an efficient connection between disc and halo gaseous components (Dettmar, 1992). In spite of a considerable variety in the morphology of DIG layers in different galaxies it is clear now that in general galaxies with higher star formation (SF) rate show more widespread and brighter DIG layers extending upto 3–5 kpc over the underlying galactic discs. Dahlem *et al.* (1995) have studied spatial correlations in distributions of radio continuum and Hα emissions in five edge-on galaxies. Two of them, NGC 891 and NGC 4631, show a very tight connection between the radio and

Hα halos, and allowed the authors to conclude that both the radio halo (relativistic electrons) and Hα halo (ionized hydrogen) are supported by SNe explosions in the underlying discs. In the other three galaxies, NGC 5775, NGC 3044 and NGC 4666, the radio and Hα extraplanar emissions are rather irregular and show a correlation with those regions of underlying discs where SF activity is enhanced. Dahlem *et al.* argued that there is a threshold energy input rate due to SNe explosions, below which extended halos cannot be suppoted. They derived the threshold as $\epsilon_{SN} \sim 10^{-4}$ erg s^{-1} cm^{-2}. This conclusion is in agreement with recent observations of Hα emission in nine edge-on galaxies, and the analysis of the DIG properties in sixteen edge-on galaxies that have been studied up to now with sufficient sensitivity (Rand, 1996). The most prominent extraplanar Hα emission shows the galaxies that have higher FIR luminosity per unit area, and moreover galaxies with an FIR luminosity less than a certain threshold value, $\epsilon_{FIR} \sim 10^{-3}$ erg s^{-1} cm^{-2} do not show bright extraplanar DIG. From a comparison of the surface SNe energy input rate found by Dahlem *et al.* (1995), and the surface FIR brightness for NGC 891 and NGC 4631 this value can be found to be equivalent to $\epsilon_{SN} \sim 0.8 \times 10^{-4}$ erg s^{-1} cm^{-2}. One should stress, however, that the surface FIR brightness given by Rand (1996) was obtained by normalizing to optical diameters of galaxies, and can suffer from considerable scatter (Dettmar, 1995).

Though the correlation of the extraplanar gas with SF rate is clear, specific mechanisms that transport gas from discs up to high z an thus support extended galactic halos are still far from being understood. A conventional point of view is that energy input from a cumulative explosion of SNe clustered in an OB associasion can provide the required energy and mass ejection rate into halos (MacLow *et al.*, 1988, Heiles, 1990). Such superexplosions can form conduits, called chimneys (Norman and Ikeuchi, 1989), through which gas from underlying galactic discs outflows. Though clear qualitatively, this scenario still does not give a convincing quantitative picture. Both an analytical treatment (Kovalenko and Shchekinov, 1985) and numerical simulations (MacLow *et al.*, 1988) predict a lower limit for the energy of a cumulative explosion in interstellar gas with exponential density distribution to form a blow-out flow. This limit is found to be of $\sim 10^{53}$–10^{54} erg for a net energy gain in an exponential interstellar gas with number density 0.03–0.1 cm^{-3} at the base and scale height 200–800 pc. Only a few OB associations in our Galaxy seem to be big enough to provide such powerfull explosions. Based on the distribution of OB associations in the Galaxy found by McKee and Williams (1993), Shchekinov (1996a) has estimated the total number of chimneys in the Galaxy to be 60, which is in agreement with the observed total number of "worm" structures (which are thought to represent chimney walls) of 118 (Koo *et al.*, 1992). Whether this number is sufficient for replenishing Galactic halo gas from the disc depends on the specific way through which chimneys provide ejection of material. If they play the role of conduits for outflow of a hot gas ($n \sim 0.01$–0.03 cm^{-3}) the total mass ejection rate is a far cry from being enough (Shchekinov, 1996a). It can be sufficient only if a considerable fraction of the supershell mass, at stages preceding the blow-out and formation of a chimney, launched as ballistic clouds due to fragmentation of a supershell as suggested by Cioffi (1986). However, this fraction must be as much as

0.3–0.5 of the total mass of a supershell to drive a considerable outflow (Shchekinov, 1996b), while in numerical simulations this fraction is shown to be about 0.05–0.1 (MacLow, *et al.*, 1988).

In such circumstances, observations are expected to bring a crucial understanding of the origin and dynamics of outflowing gas. From this point of view the recent discovery of a chimney in the Perseus arm (Normandeau *et al.*, 1996) is of great interest since it could allow us to obtain an interrelation between the mass outflow rate and the total luminosity of massive stars in OB associations, though its power seems to be less than that required for efficient replenishment of the halo gas. Observations of Hα and radio continuum emission in edge-on galaxies clearly indicate an intimate connection between the distribution of the DIG component and the local SF rate in the underlying disc (Dettmar, 1995, Dahlem *et al.*, 1995). The threshold energy unput rate $\epsilon_{\rm SN} \sim 10^{-4}$ erg s^{-1}cm^{-3} (Dahlem *et al.*, 1995) is comparable with the value of the surface mechanical luminosity of an OB association able to provide a blowing out effect. Therefore, whether a galaxy has an extended extraplanar DIG depends not only on the total SF rate, but also on the luminosity distribution of OB associations in it. In this paper we will consider this dependence, and show that even galaxies with equal SF rates can form different distributions of extraplanar gas. In this framework one can explain deviations, though rare, of the interrelation between the extension of the DIG and SF rate in the underlying disc from the general trend.

In Section 2 we present a qualitative consideration of the mass exchange rate between galactic discs and halos, and show factors which could violate the direct proportionality between the SF rate and the z-extension of the halo gas. From this point of view we briefly discuss in Section 3 possible observational evidence for such violations in two edge-on galaxies with detected extraplanar DIG.

2 EXTRAPLANAR DIG AND LUMINOSITY DISTRIBUTION OF OB ASSOCIATIONS

2.1 Energetic Requirements for a Blowout. Qualitative Considerations

It is obvious from dynamical arguments that not every superexplosion due to clustered SNe can provide a blowout into a halo. Though this issue has been studied in detail (see, e.g, Kovalenko and Shchekinov, 1985, MacLow *et al.*, 1988), we will give in this section qualitative estimations useful for the understanding of what follows. The blowout effect is a direct consequence of the preferential propagation of a shock front towards decreasing density, and was first described by Kompaneets (1960) as a break through of the exponential atmosphere. In the interstellar gas, cumulative SNe explosions with a sufficient energy input form, due to this effect, cone-shaped outflows. The energy required to provide a blowout can be estimated as the energy needed for a supershell to be a strong shock (i.e., Mach number $M \gg 1$) when its radius R_s reaches a value equal to the scale height of the ambient gas H. When this condition is not satisfied and the shock wave becomes weak at $R_s \lesssim H$, the supershell decelerates progressively and stops. For a supershell produced by a single explosion with a fixed energy E and expanding on the Sedov stage this requirement can be written as

$$v_s = \frac{2}{5}\left(\frac{E}{\rho H^3}\right)^{1/2} > 3c_s \tag{1}$$

a similar relationship written for a supershell driven by cumulative SNe explosions with a fixed mechanical luminosity L is

$$v_s = \frac{3}{5}\left(\frac{L}{\rho H^2}\right)^{1/3} > 3c_s, \tag{2}$$

where v_s is the shock velocity, ρ is the density of the ambient gas at the base, c_s is its sound speed; we require here the Mach number to be $M > 3$. From equations (1) and (2) one can obtain restrictions from below for the energy of an explosion enable to produce a blowout in these two cases

$$E > 50\lambda_R \rho H^3 c_s^2, \tag{3}$$

for a single SN explosion, and

$$E \sim L t_H > 25\lambda_R \rho H^3 c_s^2, \tag{4}$$

for multiple explosions, $t_H = H/5c_s$ is the time interval needed for a supershell to reach height $z = H$; here we introduce a factor λ_R accounting for radiative energy losses, $\lambda_R \sim$ 10–30 depending on the density and scale height of the ambient gas (Kovalenko and Shchekinov, 1985). These estimations are reasonably close to the restrictions obtained from numerical simulations (MacLow *et al.*, 1988).

To be specific we will use in what follows the value given by equation (3) as a lower limit for the blowout energy. In normalized form it can be written as

$$E_m \sim 2.5 \times 10^{51} \lambda_R \rho_1 H_{100}^3 c_{s10}^2 \text{ erg s}^{-1}, \tag{5}$$

where ρ_1 is the number density in units of 1 cm^{-3}, $H_{100} = H/100$ pc, and $c_{s10} = c_s/(10 \text{ km s}^{-1})$. For explosions in a warm neutral gas with $\rho_1 = 0.3$, $H_{100} \sim 1$ and $c_{s10} \sim 1$, this gives $\sim 10^{51}\lambda_R$ erg, exceeding by the factor λ_R the energy of a single SN explosion. However, the extended exponential H I component (the Lockman disc) with $\rho_1 \sim$ 0.01–0.03 and scale height $H_{100} \sim 5$ (Lockman *et al.*, 1986, Dickey and Lockman, 1990) increases the lower limit E_m considerably: $E_m \sim 3$–$9 \times 10^{53}\lambda_R$ erg.

2.2 *Luminosity Distribution Function of OB Associations*

These simple estimations clearly show that the ability of a galaxy to generate a powerful enough mass ejection from the disc depends on how SNe explosions correlate in space and time. In the limit of smoothly distributed SN progenitors one should expect that SN remnants will occupy a large volume fraction of the disc, forming a pervasive hot component of the interstellar gas (see the review by McKee, 1995). Though in this case the galactic fountain (Shapiro and Field, 1976) can elevate gas out of the disc, its action is not so violent as chimnyes. In the galactic fountain model hot coronal gas surrounded by a cold matrix gas suffers Rayleigh–Taylor instability to form hot bubbles rising buoyantly out of the disc. An upper limit for the mass outflow rate is determined by the mass flux $\sim f_{\rm RT}\rho_h c_s \pi R_G^2$, where $\rho_h \sim 10^{-26}$ g cm^{-3} is the density of the hot component, $c_s \sim 10^7$ cm s^{-1} is its sound speed, $f_{\rm RT}$ is the fraction of the Galactic disc covered by perturbations of sufficiently large amplitude which form uprising bubbles ($f_{\rm RT}$ can be estimated as 0.1, though this estimation is very arbitrary), and $R_G = 15$ kpc is the Galactic radius. As a result, this gives $\sim 0.3 M_\odot$ yr^{-1}. One should mention in addition that the interior of the hot bubble is at temperature ~ 0.5–1×10^6 K, corresponding to a thermally unstable state. Therefore, the cooling wave will propagate from surrounding cold gas inwards through the bubble and decrease its temperature. The velocity of the cooling wave is about $4 \times 10^3 T^{0.5}$ cm s^{-1} (three times smaller than the sound speed, Shchekinov, 1996c), and thus the bubble loses its buoyancy during a time $\sim 3R_b/c_s$ (R_b is the bubble radius). This gives for a scale height of buoyantly rising hot bubbles $H \sim 3R_b$, which seems to be smaller than 1 kpc. One can conclude therefore that only cumulative SNe explosions can provide a powerfull enough mass ejection from galactic discs, and whether SNe generate an extended gaseous halo depends on how large the clusters formed by their progenitors are.

McKee and Williams (1993) have inferred from observations of Kennicutt *et al.* (1989) the luminosity distribution function of Galactic OB associations

$$\mathcal{N}_a(S) = 5.5\left(\frac{475}{S_{49}} - 1\right), \tag{6}$$

where $S_{49} = S/(10^{49}\ {\rm s}^{-1})$ is the ionizing photon luminosity of an association and $\mathcal{N}_a(S)$ is the number of associations with a luminosity higher than S. This distribution converges to the number of luminous stars (progenitors of SNe) $\mathcal{N}_p$ contained in an association (McKee and Williams, 1993):

$$\mathcal{N}_a = 5.5\left(\frac{6200}{\mathcal{N}_p} - 1\right). \tag{7}$$

Therefore, only the most luminous associations with $\mathcal{N}_p$ close to the limiting value $\mathcal{N}_p = 6200$ can generate blowouts and eject material to high z. In our discussion of how the efficiency of the stellar disc of a galaxy to produce an extended halo depends on the characteristics of OB associations contained in the disc, we will consider the differential luminosity distribution function $\mathcal{N}_S = d\mathcal{N}_a(S)/dS$ in the form

$$\mathcal{N}_S = \mathcal{N}_0\left(\frac{S_0}{S}\right)^{\alpha+1}, \tag{8}$$

see McKee and Williams (1993). Here $\mathcal{N}_0$ is a normalizing factor with dimensions of the number of associations per unit area per unit luminosity, and S_0 is the cutoff luminosity. In what follows, we will assume the mechanical luminosity L to be proportional to the photon luminosity S and converge the distribution (8) into the distribution for L:

$$\mathcal{N}_L = \mathcal{N}_0 \left(\frac{L_0}{L}\right)^{\alpha+1} \tag{9}$$

The total luminosity per unit area given by the distribution (9) is

$$\Lambda^t = \mathcal{N}_0 L_0^2 (\alpha - 1)^{-1} (x_l^{-\alpha+1} - 1), \tag{10}$$

where $x_l = L_l/L_0$, and L_l is the lower luminosity cutoff. In our subsequent considerations $\mathcal{N}_0$, L_0 and α are free parameters.

2.3 The Threshold Mechanical Luminosity

The density, scale height and sound speed of the interstellar disc gas are the essential parameters determining the efficiensy of mechanisms elevating material out of the discs (in particular, chimneys). For an isothermal gaseous disc the scale height H is

$$H = \frac{\sigma}{2g}, \tag{11}$$

where σ is the gas velocity dispersion (thermal or turbulent) and g is the gravitational acceleration, assumed for simplicity to be constant. In turn, the velocity dispersion σ is determined by the balance of energy input and dissipation rates

$$\frac{\rho H \sigma}{t_d} = \mu \int \mathcal{N}_L L \, dL, \tag{12}$$

where t_d is the characteristic time of energy losses by the gas and μ is the fraction of explosion energy transforming into thermal energy. For t_d one can accept that the mean radiative cooling time of the interstellar gas is $\sim 10^7$ yr, and $\mu \sim 0.1$–0.3. Equation (12) uses variables averaged over volumes containing considerable numbers of OB associations. The luminosity distribution function obtained by McKee and Williams (1993) gives $220/N_p$ OB associations within 1 kpc of the Sun, with at least N_p massive stars. This means that the characteristic distance between associations is $\sim 6 \times 10^{-2}\sqrt{N_P}$ kpc, and thus averaging over volumes with a size of $2H \sim 400$ pc incorporates adequately associations with $N_p < 50$, though for more luminous associations spatial fluctuations can be important. Now the necessary conditions for the maintenance of an extended halo gas by stellar activity can be written as

$$\int_{L_m}^{L_0} \mathcal{N}_L \dot{M}_{\rm ej}(L) \, dL = \dot{M}_{\rm acc}, \tag{13}$$

with

$$L_m = 5^3 \lambda_R \rho \sigma^{3/2} H^2, \tag{14}$$

and H and σ determined by equations (11)–(12); here $\dot{M}_{ej}$ is the mass ejected by a superexplosion from an association with mechanical luminosity L and $\dot{M}_{acc}$ is the mass accretion rate per unit area for the halo gas. Apparently, $\dot{M}_{acc}$ can be estimated as $\dot{M}_{acc} \sim \rho_e H_e / t_{ff}$, where ρ_e is the density of the extraplanar gas, H_e is its scale height and $t_{ff} \sim \sqrt{2H_e/g}$ is the free-fall time. To estimate the ejection mass rate $\dot{M}_{ej}$ we assume that for a single OB association it is determined by the fraction of mass flux transferred by a supershell shock front in the vertical direction

$$\dot{M}_{ej} = 2 f_{ej} \rho v_s 4\pi R_s^2, \tag{15}$$

where $R_s = (Lt^3\rho)^{1/5}$ is the radius of the shock front and f_{ej} is the fraction of the supershell mass ejected out of the disc. Then in a steady state the ensemble of associations will produce mass ejection with the rate given by equation (13). Substituting in equation (15) v_s and R_s corresponding to a pre-blowout state, i.e., the stage at which $R_s \sim H$, one can find

$$M_{ej} = 2 f_{ej} \rho^{2/5} L^{3/5} H^{4/5} \sigma^{-2/5}, \tag{16}$$

which gives after being substituted into equation (13),

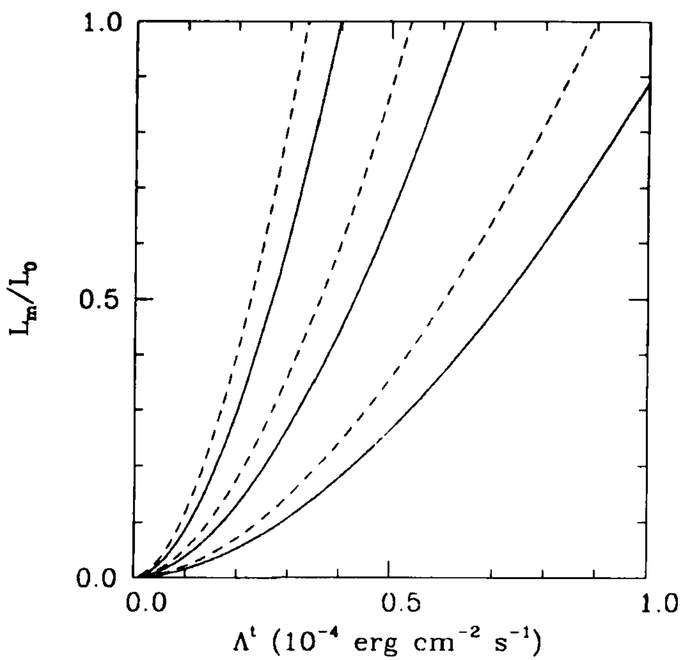

Figure 1 The dependence of the ratio of the threshold luminosity to the luminosity cutoff on the total surface luminosity of associacions Λ^t: $L_0 = 10^{40}$ erg s^{-1}, $\mathcal{N}_0 L_0 = (600\ \text{kpc}^{-2})^{-1}$; $t_d = 3 \times 10^{14}$ s; $\lambda_R = 10$; $\mu = 0.1$; $L_l = 10^{-3} L_0$; $g = 3 \times 10^{-9}$ cm s^{-2} (dahsed lines), and 10^{-8} cm s^{-2} (solid lines); $\rho = 0.1, 0.3, 1.0$ H atoms per cm^3 (left to right); $\alpha = 1.1$.

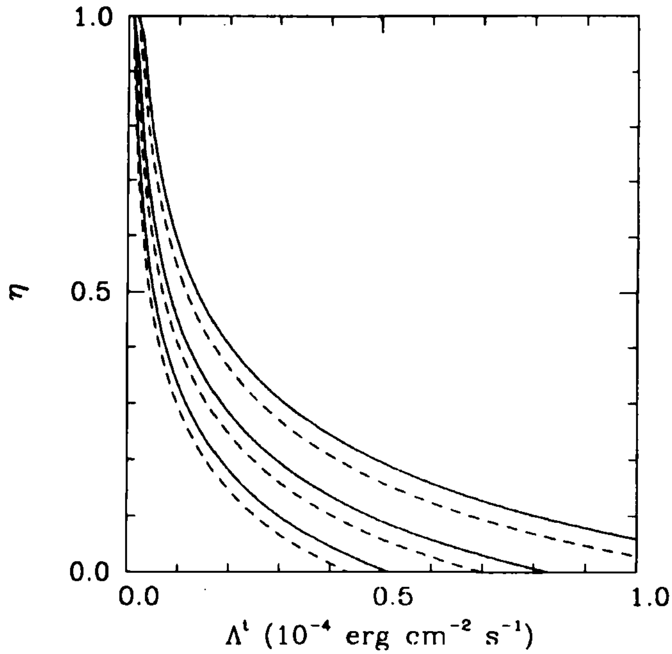

Figure 2 The efficiency of mass ejection by cumulative SNe explosions vs Λ^t for the model shown in Figure 1: $g = 3 \times 10^{-9}$ cm s^{-2} (dashed), and 10^{-8} cm s^{-2} (solid); $\rho = 0.1, 0.3, 1.0$ H atoms per cm^3 (left to right); $\alpha = 1.1$.

$$2f_{\rm ej}\mathcal{N}_0\left(\frac{\rho H^2}{\sigma}\right)^{2/5} L_0^{8/5}\left(\alpha-\frac{3}{5}\right)^{-1}\left[\left(\frac{L_m}{L_0}\right)^{-\alpha+3/5}-1\right]=\dot{M}_{\rm acc}, \quad (17)$$

with L_m determined by equation (14). It can be easily found that

$$H=\left(\frac{2\mu\Lambda^t t_d}{g\rho}\right)^{1/2}\simeq 0.6\left(\frac{\Lambda_4^t}{g_8\rho_1}\right)^{1/2}\ \text{kpc}, \quad (18)$$

$$\sigma^{1/2}=\left(\frac{2\mu\Lambda^t g t_d}{\rho}\right)^{1/4}\simeq 25\left(\frac{\Lambda_4^t g_8}{\rho_1}\right)^{1/4}\ \text{km s}^{-1}, \quad (19)$$

for $\mu = 0.1$, $t_d = 10^7$ yr, and

$$\frac{L_m}{L_0}\simeq 210\lambda_R\frac{(\mu\Lambda^t t_d)^{7/4}}{\rho^{3/4}g^{1/4}L_0}, \quad (20)$$

where $\Lambda_4^t = \Lambda^t/(10^{-4}$ erg cm^{-2} s$^{-1})$, $g_8 = g/(10^{-8}$ cm s$^{-2})$, and $\rho_1 = \rho/(1.6 \times 10^{-25}$ g cm$^{-3})$. Figure 1 shows the dependence of L_m/L_0 on the total surface luminosity Λ^t for $\alpha = 1.1$ and different values of ρ and g.

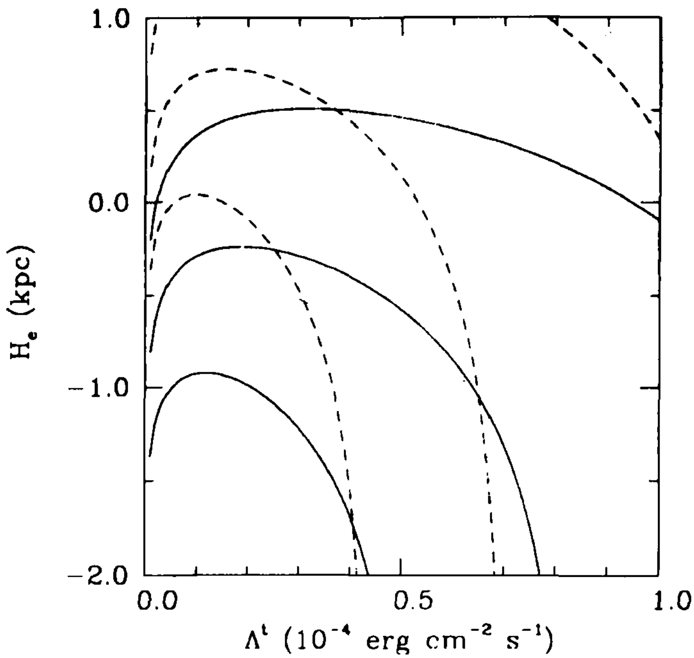

Figure 3 The characteristic thickness of the extended halo gas vs Λ^t for the model shown in Figure 1: $g = 3 \times 10^{-9}$ cm s^{-2} (dashed), and 10^{-8} cm s^{-2} (solid); $\rho = 0.1$, 0.3, 1.0 H atoms per cm^3 (bottom to top); $\alpha = 1.1$.

It is seen that as the total luminosity increases the threshold luminosity for a single association L_m grows rapidly and reaches the cutoff luminosity L_0. This means in turn that the efficiency of stellar activity to eject material out of the disc, i.e., the fraction of the mechanical luminosity of associations which goes to support the extended gaseous halo

$$\eta = \frac{\int_{L_m}^{L_0} \mathcal{N}_L L\, dL}{\int_{L_l}^{L_0} \mathcal{N}_L L\, dL}, \tag{21}$$

decreases with Λ^t, see Figure 2.

Therefore, higher stellar activity, i.e., higher Λ^t, does not necessarily result in more extended and brighter extraplanar DIG. Physical reasons of that are clearly seen from equations (14), (18) and (19): the larger the surface luminosity Λ^t, the thicker and hotter is the gaseous disc, and the stronger are the requirements for a cumulative SNe explosion to blow out the disc. The dependence of the thickness of the extended gaseous halo derived from equation (17) with $\dot{M}_{\rm acc} \sim \rho_e H_e / t_{\rm ff}$ on the total luminosity of associations per unit area is shown in Figure 3 for $\rho_e = 3 \times 10^{-3}$ H atoms per cm^{-3}: thus the function $H_e(\Lambda^t)$ is not a monotonic function, and after reaching a maximal value decreases rapidly with Λ^t. Note that for higher densities in the disc ρ, H_e is larger at equal values of Λ^t: such a dependence is a direct

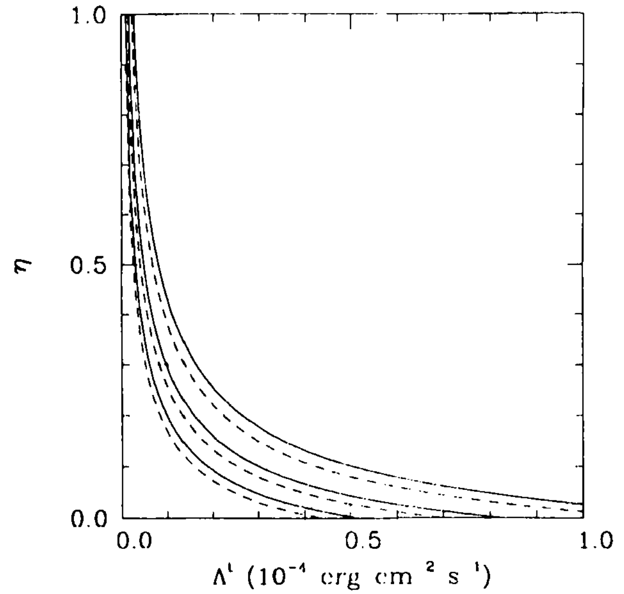

Figure 4 The efficiency of mass ejection by cumulative SNe explosions vs Λ^t for the model with $\alpha = 1.3$: $g = 3 \times 10^{-9}$ cm s^{-2} (dashed), and 10^{-8} cm s$^-2$ (solid); $\rho = 0.1, 0.3, 1.0$ H atoms per cm^3 (left to right); other parameters are the same as in Figure 1.

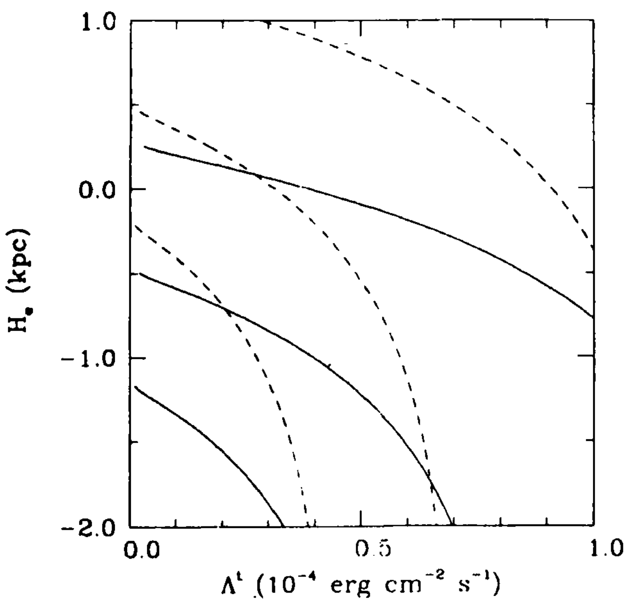

Figure 5 The characteristic thickness of the extended halo gas vs Λ^t for the model shown in Figure 4: $g = 3 \times 10^{-9}$ cm s^{-2} (dashed), and 10^{-8} cm s^{-2} (solid); $\rho = 0.1, 0.3, 1.0$ H atoms per cm^3 (bottom to top); $\alpha = 1.3$; other parameters are the same as in Figure 1.

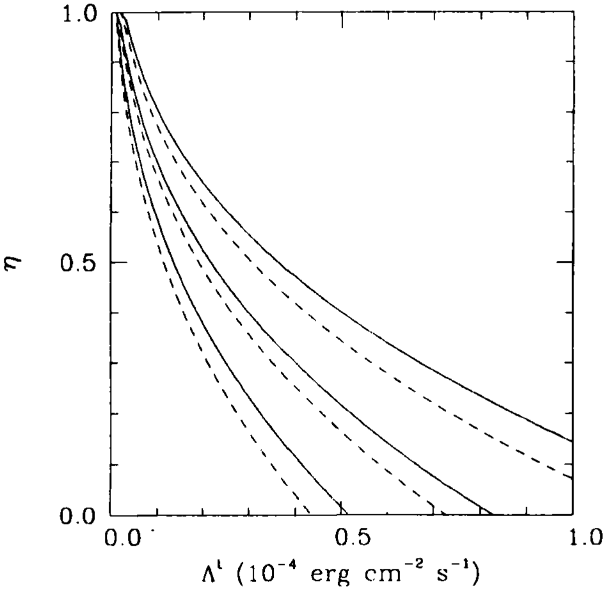

Figure 6 The efficiency of mass ejection by cumulative SNe explosions vs Λ^t for the model with $\alpha = 0.8$: $g = 3 \times 10^{-9}$ cm s^{-2} (dashed), and 10^{-8} cm s^{-2} (solid); $\rho = 0.1, 0.3, 1.0$ H atoms per cm^3 (left to right); other parameters are the same as in Figure 1.

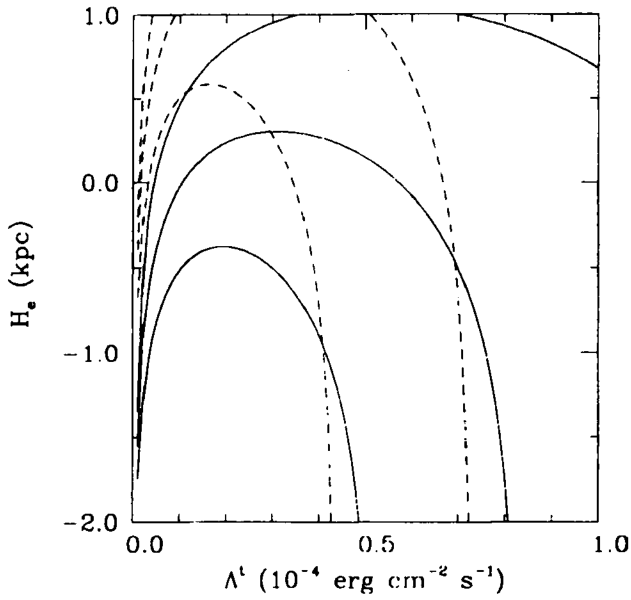

Figure 7 The characteristic thickness of the extended halo gas vs Λ^t for the model shown in Figure 6: $g = 3 \times 10^{-9}$ cm s^{-2} (dashed), and 10^{-8} cm s^{-2} (solid); $\rho = 0.1, 0.3, 1.0$ H atoms per cm^3 (bottom to top); $\alpha = 0.8$; other parameters are the same as in Figure 1.

consequence of the inverse dependence of the thickness H, and the thermal velocity dispersion σ of the disc gas: $H \propto \rho^{-1/2}$ and $\sigma \propto \rho^{-1/2}$ (equations (18), (19)). This makes clear the decrease of the threshold luminosity L_m/L_0 (Figure 1), and the increase of the mass ejection efficiency η (Figure 2) with density in the disc.

For the luminosity distribution of associations with $\alpha = 1.3$, i.e., with relatively smaller contribution of highly luminous associations the efficiency of mass ejection η decreases (at $\Lambda^t > 2 \times 10^{-6}$ erg cm^{-2} s^{-1}) as shown in Figure 4, and as a result the extension of the halo gas at equal surface luminosity Λ^t decreases. Note that in this case H_e is a monotonically decreasing function of the luminosity (except for a narrow region of $\Lambda^t < 2 \times 10^{-6}$ erg cm^{-2} s^{-1}, not indicated here, where it behaves as $H_e \propto (\Lambda^t)^{12/5}$), Figure 5. This is due to the fact that at larger α the contribution of more luminous associations which mostly provide blowouts is smaller.

This circumstance is confirmed by the model with $\alpha = 0.8$ (Figures 6 and 7) with increased contribution of luminous associations. It is seen that at a given total luminosity Λ^t the efficiency of mass ejection η, and respectively, the extension of the halo gas H_e, is higher than in models with $\alpha > 0.8$. However, as in previous models at large luminosities, $\Lambda^t > 0.3$–0.5×10^{-4} erg cm^{-2} s^{-1}, when the threshold luminosity (Figure 1) reaches the cutoff value L_0, both η and H_e decrease.

A distinguishing feature of this model is that the interval of luminosities (at the lower side) Λ^t where the extension of the extraplanar gas increases is larger: $\Lambda^t \simeq 0.25$–0.5×10^{-4} erg cm^{-2} s^{-1} for a density $\rho = 0.1$–1 H atoms per cm^3, respectively, than in models with $\alpha > 1$ where $\Lambda^t \simeq 0.1$–0.2×10^{-4} erg cm^{-2} s^{-1}.

3 DISCUSSION

In the simple model presented in this paper we have shown that the interrelation between the extension of extraplanar gas (and as a consequence, the brightness of DIG) and the total surface mechanical (and FIR) luminosity of OB associations does not follow a monotonic law: at high luminosities, $\Lambda^t > 0.3$–0.5×10^{-4} erg cm^{-2} s^{-1}, the thickness of the extraplanar gas layer decreases sharply because the hot and thick disc confines the energy released by SNe. In this connection one should mention the case of the edge-on galaxy NGC 4013: with a rather high total (1.4×10^{43} erg s^{-1}) and surface (2.6×10^{40} erg kpc^{-2} s^{-1}) FIR luminosity, comparable with the total (2×10^{43} erg s^{-1}) and surface (1.8×10^{40} erg kpc^{-2} s^{-1}) FIR luminosity in NGC 4631, NGC 4013 has a considerably weaker ($H_e \lesssim 900$ pc) extraplanar DIG layer than NGC 4631 ($H_e \sim 2$–5 kpc) (Rand *et al.*, 1990, Rand, 1996). Two reasons can be shown to explain such a drastic difference: either the parameters determining the extension of halo gas at a given luminosity (namely, gas density in the disc, gravitational acceleration, and the slope of the luminosity distribution function of OB associations) differ considerably for these galaxies, or NGC 4013 represents the decreasing part of the curve $H_e(\Lambda^t)$, while NGC 4631 corresponds to the maximum of $H_e(\Lambda^t)$.

Being based on estimations of the order of magnitude of the energy balance averaged over large scales this conclusion of necessity has a qualitative character. It is obvious that on spatial and temporal scales corresponding to scales in which the interstellar gas disturbed by a cumulative SNe explosion relaxes to an average state, considerable fluctuations in energy release and hydrodynamical motions can take place with an enhanced local mass ejection rate. For example, in a steady ISM corresponding to the model shown in Figure 3 with $\rho_1 = 0.3$, $g_8 = 1$ (median solid line) and average $\Lambda_4^t = 0.8$, an increase of Λ^t localized in time and space by a factor of 3 will drive a blowout with proportionally increased mass ejection rate, since in the *equilibrium* state at given average parameters the efficiency of ejection η is high, $\eta \sim 0.7$. Variations in stellar activity are definitely important for explanations of the origin of extraplanar gas: NGC 891 with a prominent DIG and clearly seen large-scale asymmetry in its distribution (Dettmar, 1992) is a good example. The observed correlation between SF rate and extension of Hα halos in edge-on galaxies suggests that either the total luminosity in these galaxies Λ^t corresponds to a growing part of the dependence $H_e(\Lambda^t)$, or the main contribution to DIG comes from spatially localized stellar activity which exceeds substantially the averaged SF characteristics and thus violates the interrelations for the steady homogeneous models shown above.

Acknowledgements

We are grateful to R.-J. Dettmar, A. Ferrara and U. Lisenfeld for numerous discussions of different aspects of the disc-halo connection in spiral galaxies. This work was supported by the Russian Foundation of Basic Research under grant 94–02–05016–a, and in part (YS) by an IAU travel grant.

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